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AVIRIS SPECTRA CORRELATED WITH THE CHLOROPHYLL CONCENTRATION OF A FOREST CANOPY

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1. INTRODUCTION

Imaging spectrometers have many potential applications in the environmental sciences. One of the more promising applications is that of estimating the biochemical concentrations of key foliar biochemicals in forest canopies (Peterson *et al.*, 1988; Wessman *et al.*, 1989; Johnson and Peterson, 1991). These estimates are based on spectroscopic theory developed in agriculture (Curran, 1989) and could be used to provide the spatial inputs necessary for the modelling of forest ecosystem dynamics and productivity (Committee on Earth Sciences, 1989). Several foliar biochemicals are currently under investigation ranging from those with primary absorption features in visible to middle infrared wavelengths (e.g., water, chlorophyll) to those with secondary to tertiary absorption features in this part of the spectrum (e.g., nitrogen, lignin). The foliar chemical of interest in this paper is chlorophyll; this is a photoreceptor and catalyst for the conversion of sunlight into chemical energy and as such plays a vital rôle in the photochemical synthesis of carbohydrates in plants.

The aim of the research reported here was to determine if the chlorophyll concentration of a forest canopy could be correlated with the reflectance spectra recorded by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS).

2. DATA COLLECTION AND METHODS

The study site is located 35 km NE of Gainesville, Florida. Fourteen plots (50 X 50 m) had been established in a mature stand of slash pine. Half of these plots had been fertilised and the other half were controls (Gholz *et al.*, 1991). Each plot had a uniform canopy structure and similar background.

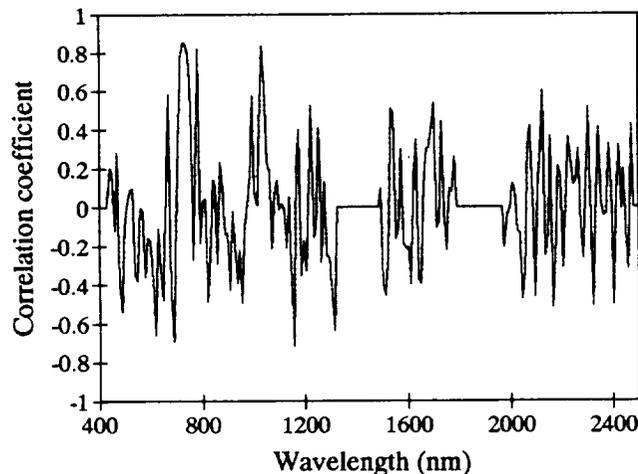
In July 1992 twenty needle samples were collected from the upper canopy of each of the 14 plots. Chlorophyll concentration was determined in the laboratory using standard spectrophotometry of tissue extracts in a 90% acetone solution (Mackinney, 1941). The mean chlorophyll concentrations were 2.10 mg g⁻¹ (σ 0.82 mg g⁻¹) and 1.33 mg g⁻¹ (σ 0.40 mg g⁻¹) for the fertilised and control plots respectively.

Four images of the study site were recorded by the AVIRIS within a 50 minute period on the 8th July 1992. These images were atmospherically corrected to 'scaled surface reflectance' by The Centre for the Study of the Earth from Space (CSES) at the University of Colorado in Boulder using the 'Atmospheric Removal Program' (ATREM) (Gao *et al.*, 1992). The 14 plots were located within each image using an affine transformation calculated from ground control points. Two check points indicated an average error of less than one pixel. A reflectance spectrum for each plot was extracted from each of the four images. These spectra were averaged by plot and transformed to a first derivative of the reflectance values.

3. THE CORRELATION BETWEEN FIRST DERIVATIVE REFLECTANCE AND CHLOROPHYLL CONCENTRATION

Correlation coefficients between first derivative reflectance and chlorophyll concentration were calculated for each AVIRIS waveband (Figure 1).

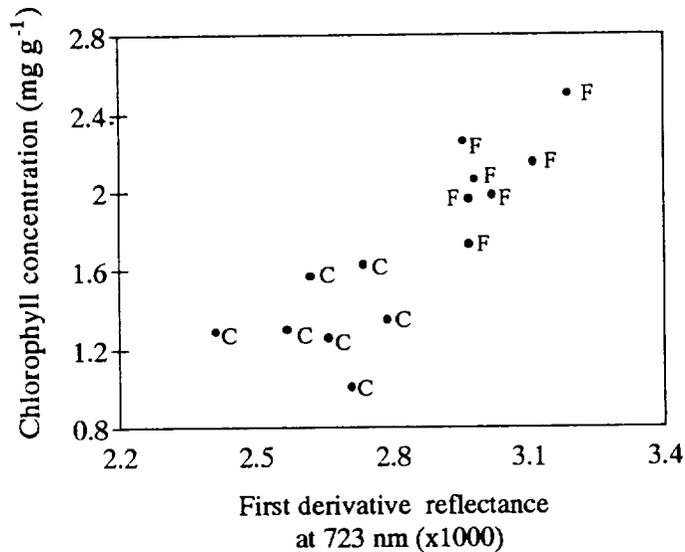
Figure 1. Correlation coefficients between first derivative reflectance and chlorophyll concentration for 14 plots. Note that the very low signals in the water absorption bands have been rescaled to zero.



The maximum correlation coefficient is 0.85 and occurs at a wavelength of 723 nm. This is located on the edge of the chlorophyll absorption feature in a spectral region used by others for the spectral estimation of chlorophyll concentration (Gates 1980; Baret *et al.*, 1987; Curran *et al.*, 1990).

First derivative reflectance data at 723 nm were extracted from the first derivative spectra and plotted against chlorophyll concentration (Figure 2). The relationship between these two variables is not only near linear it is also functionally direct. An *increase* in chlorophyll concentration will result in *increases* in the depth of the absorption feature, the steepness of its long wavelength edge and thereby the first derivative of reflectance.

Figure 2. First derivative reflectance at 723 nm plotted against chlorophyll concentration for 14 plots, of which 7 are (C)ontrol and 7 are (F)ertilised.



Stepwise regression was used to explore further the relationship between first derivative reflectance and chlorophyll concentration (Table).

Table. The results of a stepwise regression analysis between first derivative reflectance and chlorophyll concentration.

Step No.	Waveband (nm)	R ²	Change in R ²
1	723	0.73	0.73
2	2371	0.87	0.14
3	1552	0.96	0.09

The first step of the regression analysis selected the wavelength in which there was the largest correlation between first derivative of reflectance and chlorophyll concentration (723 nm); this accounted for 73% of the variation in chlorophyll concentration. Subsequent selections were for wavelengths reported to be associated with other foliar biochemical constituents (Williams and Norris, 1987). Research is in progress to explain these subsequent wavelength selections.

4. CONCLUSION

This is the first study to report a correlation between the AVIRIS spectra and chlorophyll concentration. The challenge ahead is to correlate the AVIRIS spectra with other foliar biochemicals (e.g., water, nitrogen, lignin, cellulose) and then to use this experience as a basis for the design of methodologies for the *estimation* of foliar biochemical concentrations.

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REFERENCES

- Baret, F., Champion, L., Guyot, G., Podaire, L. 1987. Monitoring wheat canopies with a high spectral resolution radiometer. *Remote Sensing of Environment*, 22:367-378.
- Committee on Earth Sciences. 1989. *Our Changing Planet: The FY90 Research Plan (The U.S. Global Change Research Program)*, U.S. Department of Interior, Reston, VA.
- Curran, P.J. 1989. Remote sensing of foliar chemistry. *Remote Sensing of Environment*, 30:271-278.
- Curran, P.J., Dungan, J.L., Gholz, H.L. 1990. Exploring the relationship between reflectance red edge and chlorophyll content in slash pine. *Tree Physiology*, 7:33-48.
- Gao, B-C, Heidebrecht, K.B. and Goetz, A.F.H., 1992, *Atmospheric removal program (ATREM) users guide*. Centre for the Study of the Earth from Space, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder.
- Gates, D.M. 1980. *Biophysical Ecology*. Springer-Verlag, New York.
- Gholz, H.L., Vogel, S.A., Cropper, W.P. Jr., McKelvey, K., Ewel, K.C., Teskey, R.O., Curran P.J. 1991. Dynamics of canopy structure and light interception in *Pinus elliottii* stands, North Florida. *Ecological Monographs*, 61, 33-51.
- Johnson, L.F., Peterson, D.L. 1991. AVIRIS observations of forest ecosystems along the Oregon transect. *Proceedings of the Third Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop*. Ed. R.O. Green. May 20-21 1991. JPL publication 91-28, Pasadena, CA, 190-199.
- Mackinney, G. 1941. Absorption of light by chlorophyll solutions. *Journal of Biological Chemistry*, 140:315-322.
- Peterson, D.L., Aber, J.D., Matson, P.A., Card, D.H., Swanberg, N.A., Wessman, C.A., Spanner, M.A. 1988. Remote sensing of forest canopy and leaf biochemical contents. *Remote Sensing of Environment*, 24:85-108.
- Wessman, C.A., Aber, J.D., Peterson, D.L. 1989. An evaluation of imaging spectrometry for estimating forest canopy chemistry. *International Journal of Remote Sensing*, 10:1293-1316.
- Williams, P. and Norris, K. 1987. *Near infrared technology in the agricultural and food industries*. American Association of Cereal Chemists Inc., St. Paul, MN.